

**Supersymmetric analysis and predictions based on the CDF  
 $ee\gamma\gamma + \cancel{E}_T$  event**S. Ambrosanio<sup>\*,1</sup>, G. L. Kane<sup>2</sup>, Graham D. Kribs<sup>3</sup>, Stephen P. Martin<sup>4</sup>*Randall Physics Laboratory, University of Michigan,  
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Argonne, IL 60439***Abstract**

We have analyzed the single  $ee\gamma\gamma + \cancel{E}_T$  event at CDF and found that the expected rate and kinematics are consistent with selectron pair production. We consider two classes of general low-energy supersymmetric theories, where either the lightest neutralino (“neutralino LSP” scenario) or the gravitino (“light gravitino” scenario) is the lightest supersymmetric particle. The parameter space of the supersymmetric Lagrangian is tightly constrained by the kinematics of the event and the branching ratios for the necessary decay chain of the selectron. We identify a region of the parameter space satisfying all low-energy constraints, and consistent with the selectron interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event. We discuss other supersymmetric processes at Fermilab Tevatron and at CERN LEP in both scenarios that could confirm or exclude a supersymmetric explanation of the event, and that could distinguish between the neutralino LSP and the light gravitino scenarios.

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# Introduction

The CDF collaboration at the Fermilab Tevatron collider has reported [1] an  $ee\gamma\gamma + \cancel{E}_T$  event that does not seem to have a Standard Model (SM) interpretation. We confirm that the event is consistent with the kinematics of selectron pair production ( $p\bar{p} \rightarrow \tilde{e}^+\tilde{e}^-$ ), with a mass  $m_{\tilde{e}}$  in the range 80 to 130 GeV, and about the expected cross section for one event in  $100 \text{ pb}^{-1}$  of data. In the neutralino LSP scenario, the selectron  $\tilde{e}$  must decay mainly into the next-to-lightest neutralino  $\tilde{\chi}_2^0$  and an electron ( $\tilde{e} \rightarrow \tilde{\chi}_2^0 e$ ), followed by  $\tilde{\chi}_2^0$  decay to the lightest neutralino  $\tilde{\chi}_1^0$  through the radiative channel  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$  [2, 3, 4]; this chain is expected to have a high probability if  $\tilde{\chi}_1^0$  is the lightest supersymmetric particle (LSP) and is Higgsino-like while  $\tilde{\chi}_2^0$  is gaugino-like. Alternatively, if there is a very light gravitino  $\tilde{G}$  [5] with a mass  $m_{\tilde{G}} < 1 \text{ keV}$ , then the selectron decay is interpreted as  $\tilde{e} \rightarrow \tilde{\chi}_1^0 e$  followed by  $\tilde{\chi}_1^0 \rightarrow \tilde{G} \gamma$ . While we were writing this paper, Ref. [6] appeared. It also discusses the light gravitino scenario, but not the neutralino LSP scenario, for the CDF  $ee\gamma\gamma + \cancel{E}_T$  event.

We determine a set of supersymmetric soft-breaking parameters, superpotential parameters, and  $\tan\beta$  values that give masses and event rates consistent with the  $ee\gamma\gamma + \cancel{E}_T$  event, as well as all other theoretical and phenomenological constraints, including LEP1–1.3 data. Then we calculate rates for production and decay of selectrons, charginos, neutralinos and associated processes. Finding any of these would greatly strengthen the supersymmetric interpretation. We illustrate how to experimentally distinguish the two supersymmetric scenarios (where the LSP is either  $\tilde{\chi}_1^0$  or  $\tilde{G}$ ). When  $\tilde{\chi}_1^0$  is the LSP, we find the soft-breaking masses  $M_1$ ,  $M_2$  do not satisfy the gaugino mass unification condition  $M_1 \simeq 5/3 \tan^2 \theta_W M_2$ , but rather  $M_1 \simeq M_2$ . Interestingly, the resulting models are like those that give a supersymmetric interpretation of the LEP  $R_b$  excess, but we will not pursue that question in detail in this paper. In the light gravitino scenario, one can maintain the gaugino mass unification relation. Our main result is to establish the validity of the supersymmetric interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event by identifying the region of parameter space that satisfies the kinematic, cross section, and branching ratio constraints. Then we provide predictions for events whose presence (absence) would confirm (exclude) the supersymmetric interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event.

We perform our analysis in terms of a general supersymmetric Lagrangian at the electroweak scale, with no unification assumptions nor significant assumptions about the unknown superpartner masses. In low energy supersymmetry, as in the Standard Model, masses are unknown until they are measured. Some cross sections only depend on the mass of the produced particles and are thus unique, while others depend on masses of exchanged sparticles and can have a range, which we report. In some cases we show a scatter plot which is produced by allowing unknown masses (and  $\tan\beta$ ) to take on the range of values allowed by theoretical and phenomenological constraints, and the  $ee\gamma\gamma + \cancel{E}_T$  event. The different sets of supersymmetric parameters (masses and couplings) are often referred to as “models”, though they all parameterize the same Lagrangian.

## Kinematics of the $ee\gamma\gamma + \cancel{E}_T$ event

We have investigated the kinematics of this event, under the hypothesis that it can be ascribed to selectron pair production  $q\bar{q} \rightarrow Z^*, \gamma^* \rightarrow \tilde{e}^+ \tilde{e}^-$  with a subsequent 2-body decay for each selectron:  $\tilde{e} \rightarrow e\tilde{X}_2$  followed by  $\tilde{X}_2 \rightarrow \tilde{X}_1\gamma$ . Here  $\tilde{X}_1$  ( $\tilde{X}_2$ ) is the lightest (next-to-lightest) neutral, odd R-parity, fermion. We assume exact R-parity conservation, so that  $\tilde{X}_1$  is an absolutely stable LSP. One can then identify two possible scenarios. In the first, “neutralino LSP” scenario,  $\tilde{X}_1, \tilde{X}_2$  are the two lightest neutralino states,  $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ , i.e. mixtures of photino, Zino, and Higgsinos. In the second, “light gravitino” scenario,  $\tilde{X}_2$  is the lightest neutralino  $\tilde{\chi}_1^0$ , and  $\tilde{X}_1$  is a very light gravitino  $\tilde{G}$ , which can be treated as massless for all kinematical purposes. Under the assumptions that each  $\tilde{e}$ ,  $\tilde{X}_2$  is on mass shell and that all decays occur close to the apparent vertex, we can find some non-trivial constraints. (The latter assumption need not hold in the light gravitino scenario, as we shall see.) First, we observe that only one pairing of electron and photon [1] gives consistent kinematics for  $m_{\tilde{e}} \lesssim 130$  GeV. We also find the following constraints on the unknown sparticle masses:  $m_{\tilde{e}} > 80$  GeV;  $38 \text{ GeV} \lesssim m_{\tilde{X}_2} \lesssim \min[1.12 m_{\tilde{e}} - 37 \text{ GeV}, 95 \text{ GeV} + 0.17 m_{\tilde{X}_1}]$ ;  $m_{\tilde{X}_1} \lesssim \min[1.4 m_{\tilde{e}} - 105 \text{ GeV}, 1.6 m_{\tilde{X}_2} - 60 \text{ GeV}]$ . In particular, the event is consistent with a massless  $\tilde{X}_1$  (e.g. in the light gravitino scenario). The upper limits on  $m_{\tilde{X}_2}$  depend weakly on a conservative upper bound on the invariant mass of the selectron pair  $m_{\tilde{e}^+\tilde{e}^-}$  following from the cross section; this also requires that  $m_{\tilde{e}}$  is not

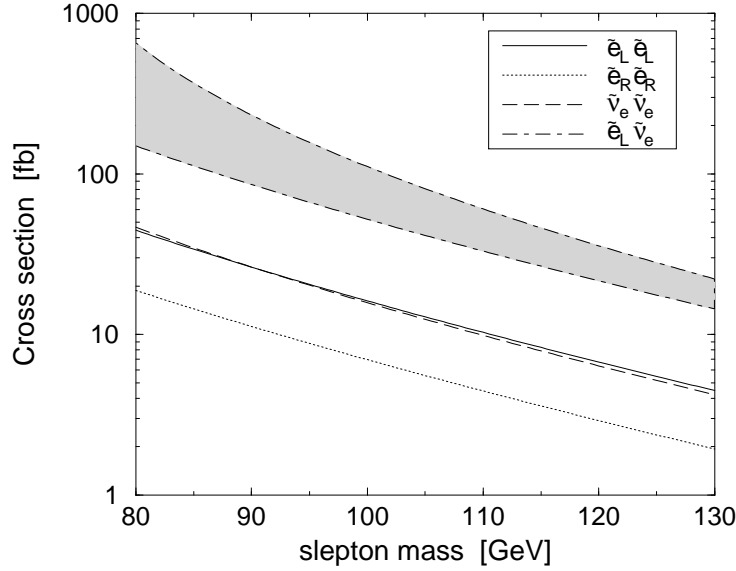


Figure 1: Cross sections for  $\tilde{e}_L \tilde{e}_L$ ,  $\tilde{e}_R \tilde{e}_R$ ,  $\tilde{\nu}_e \tilde{\nu}_e$ , and  $\tilde{e}_L \tilde{\nu}_e$  production at the Tevatron for  $\sqrt{s} = 1.8$  TeV versus  $m_{\tilde{e}_L}$ ,  $m_{\tilde{e}_R}$ ,  $m_{\tilde{\nu}_e}$ , and  $m_{\tilde{e}_L}$  respectively. The cross sections depend only on the masses of the sleptons; the shaded band for  $\tilde{e}_L \tilde{\nu}_e$  corresponds to the allowed range of  $m_{\tilde{\nu}_e}$  for a fixed  $m_{\tilde{e}_L}$ , that can be parameterized by  $\tan \beta$ . The lower (upper) dot-dashed line corresponds to  $\tan \beta = 1$  (3).

larger than roughly 130 GeV. We also find that the kinematics of the event give a lower bound on  $m_{\tilde{e}^+ \tilde{e}^-}$  of about 275 GeV. These constraints are based on measured quantities that have experimental errors, and can be sharpened with a more detailed study of the event. Further constraints arise in particular interpretations described below. (In principle, another possible origin of the  $ee\gamma\gamma + \cancel{E}_T$  event is chargino pair production, but dynamical and kinematical considerations tend to disfavor this process; we will discuss this in Ref. [7].)

## Cross sections

In Fig. 1, we display the cross sections for slepton production [8, 9] at the Tevatron ( $\sqrt{s} = 1.8$  TeV) in the mass region suggested by the kinematics. The slepton production cross sections depend only on the masses of the sleptons, so the cross sections decouple from analyses of particular scenarios (neutralino LSP or light gravitino). For reference, CDF and D0 each have

about  $100 \text{ pb}^{-1}$  of integrated luminosity, so the one event level is at  $\sigma = 10 \text{ fb}$ .

Typically  $\sigma(\tilde{e}_L \tilde{e}_L) \approx 2.3\sigma(\tilde{e}_R \tilde{e}_R)$  for equal mass sleptons. If the  $ee\gamma\gamma + \cancel{E}_T$  event is from  $\tilde{e}_L$  production then the  $\tilde{e}_L \tilde{\nu}_e$  channel is definitely accessible since  $\tilde{e}_L$  and  $\tilde{\nu}_e$  are in an  $\text{SU}(2)_L$  doublet and thus related by the sum rule  $m_{\tilde{e}_L}^2 = m_{\tilde{\nu}_e}^2 + M_W^2 |\cos 2\beta|$ , with  $\tan \beta > 1$ ; hence  $m_{\tilde{\nu}_e} < m_{\tilde{e}_L}$ . Further, if  $m_{\tilde{e}_L}$  and  $m_{\tilde{\nu}_e}$  were measured separately, then the sum rule provides an experimental determination of  $\tan \beta$ . If the event is from  $\tilde{e}_R$  production, then  $m_{\tilde{e}_L}$  and  $m_{\tilde{\nu}_e}$  are not determined by the event. In many unified models one finds  $m_{\tilde{e}_R} < m_{\tilde{e}_L}$ , but this is not required [10].

Although we mainly discuss selectron production in the following, if lepton family universality is at least approximately valid in supersymmetry, then our discussion also applies to  $\mu$  and  $\tau$  events. In particular, second and third family sleptons (smuon, stau) would have the same production cross sections as the selectron if the masses were the same. Slepton mass degeneracy is not an unreasonable expectation, and is suggested by the lack of flavor changing neutral currents. An interesting signature of supersymmetry emerges by considering second and third family slepton production. Since the leptons from slepton decay will always have the same flavor, one would expect no events with a signature  $e\mu\gamma\gamma$  except for the small contribution from stau production when the  $\tau$ 's decay leptonically. However, the rate for  $e\mu\gamma\gamma$  is only  $1/20$  the rate for same-flavor leptons  $ee\gamma\gamma$  or  $\mu\mu\gamma\gamma$ . Contrast this rate with the very small SM process  $WW\gamma\gamma$ , which has a rate for  $e\mu\gamma\gamma$  that is a factor of 2 *greater* than either  $ee\gamma\gamma$  or  $\mu\mu\gamma\gamma$ . Hence, the eventual observation of a much reduced fraction of  $e\mu\gamma\gamma$  events over  $ee\gamma\gamma$  would strongly support a supersymmetric interpretation.

## The neutralino LSP interpretation

The Minimal Supersymmetric Standard Model (MSSM) has a particle spectrum including the SM particles plus their superpartners, with the SM gauge group  $\text{SU}(3)_c \times \text{SU}(2)_L \times \text{U}(1)_Y$ . We generally follow the notation and conventions of Ref. [11], including that for the sign of  $\mu$ . We do not impose gaugino mass unification ( $M_1 = (\alpha_1/\alpha_2)M_2 = (\alpha_1/\alpha_3)M_3$ ), nor scalar mass unification – we make no assumptions about high scale ( $M_{\text{GUT}}$ ) physics. In fact, we can test

gaugino mass unification, as explained below.<sup>1</sup>

The  $ee\gamma\gamma + \cancel{E}_T$  does have a consistent neutralino LSP interpretation, with masses and couplings that are tightly constrained. In order to have the decay  $\tilde{e} \rightarrow \tilde{\chi}_2^0 e$  dominate,  $\tilde{\chi}_2^0$  must be largely gaugino (i.e.  $\tilde{\gamma}$ ,  $\tilde{Z}$  rather than Higgsino). In order to have the radiative decay  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$  dominate, it is necessary to have one of  $\tilde{\chi}_1^0, \tilde{\chi}_2^0$  be mainly gaugino and the other mainly Higgsino [2, 3, 4]. Since only the gaugino will couple to  $\tilde{e}e$ , this uniquely fixes  $\tilde{\chi}_1^0$  to be mainly Higgsino,  $\tilde{\chi}_2^0$  to be mainly gaugino. An examination of the neutralino mass matrix [12, 13] then leads to the region of parameter space  $\tan\beta \simeq 1$  and  $M_1 \simeq M_2$ . In the limit when these relations are exact, one neutralino is a pure Higgsino  $\tilde{\chi}_1^0 \simeq \tilde{H}_b^0$  (where  $\tilde{H}_a^0, \tilde{H}_b^0$  are the so-called “antisymmetric”, “symmetric” combinations of  $\tilde{H}_1^0$  and  $\tilde{H}_2^0$ ) with a mass  $|\mu|$ , and another is a pure photino with a mass  $M_1 = M_2$ . The other two neutralino states are Zino-Higgsino mixtures with masses  $m_{\tilde{H}_a^0 - \tilde{Z}} = \frac{1}{2} \left| M_2 + \mu \pm \sqrt{(M_2 - \mu)^2 + 4M_Z^2} \right|$ . The two chargino masses are given by the same relation with  $M_Z \rightarrow M_W$ . In order to obtain the desired hierarchy of neutralino masses such that  $m_{\tilde{H}_b^0} < m_{\tilde{\gamma}} < m_{\tilde{H}_a^0 - \tilde{Z}}$ ,  $\mu$  must be negative, and  $|\mu|$  must be smaller than  $M_1 \simeq M_2$ . Also, the kinematics of the event give  $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} \gtrsim 30$  GeV, and  $m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_3^0}$  must be sufficiently heavy to not have  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  and  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  pairs seen at LEP1.3. This almost fixes the allowed ranges of  $|\mu|$  and  $M_1 \simeq M_2$ .

If we try to move away from  $M_1 \simeq M_2$  (e.g. toward the SUGRA-MSSM), it is still possible to have a large  $\text{BR}(\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma)$  when  $M_1 \simeq M_2/2 \simeq -\mu$  ( $\mu < 0$ ) and small  $\tan\beta$  [4], but then  $m_{\tilde{\chi}_2^0}$  is near  $m_{\tilde{\chi}_1^0}$  and the kinematical properties of the event cannot be satisfied; if one increases the mass difference by increasing  $\tan\beta$ , the radiative branching ratio drops. Thus it appears to be very difficult if not impossible to have a SUGRA-MSSM interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event.

The analytical limits discussed above point to a specific region of the supersymmetric parameter space that we have explored with complete numerical calculations. We require the combined branching ratio  $\tilde{e}^+ \tilde{e}^- \rightarrow e^+ e^- \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)$  to be greater than 50%, consistent with the  $ee\gamma\gamma + \cancel{E}_T$  event. The inputs include  $M_1, M_2, \mu, \tan\beta$  to obtain the chargino and neutralino masses and mixings, in addition to the squark and slepton sector, which enter the branching

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<sup>1</sup>We use the term “SUGRA-MSSM” to refer to supersymmetric models with gaugino and scalar mass unification.

$ee\gamma\gamma + \cancel{E}_T$ constraints on supersymmetric parameters	
$\tilde{e}_L$	$\tilde{e}_R$
$100 \lesssim m_{\tilde{e}_L} \lesssim 130 \text{ GeV}$	$100 \lesssim m_{\tilde{e}_R} \lesssim 112 \text{ GeV}$
$50 \lesssim M_1 \lesssim 92 \text{ GeV}$	$60 \lesssim M_1 \lesssim 85 \text{ GeV}$
$50 \lesssim M_2 \lesssim 105 \text{ GeV}$	$40 \lesssim M_2 \lesssim 85 \text{ GeV}$
$0.75 \lesssim M_2/M_1 \lesssim 1.6$	$0.6 \lesssim M_2/M_1 \lesssim 1.15$
$-65 \lesssim \mu \lesssim -35 \text{ GeV}$	$-60 \lesssim \mu \lesssim -35 \text{ GeV}$
$0.5 \lesssim  \mu /M_1 \lesssim 0.95$	$0.5 \lesssim  \mu /M_1 \lesssim 0.8$
$1 \lesssim \tan\beta \lesssim 3$	$1 \lesssim \tan\beta \lesssim 2.2$
$33 \lesssim m_{\tilde{\chi}_1^0} \lesssim 55 \text{ GeV}$	$32 \lesssim m_{\tilde{\chi}_1^0} \lesssim 50 \text{ GeV}$
$58 \lesssim m_{\tilde{\chi}_2^0} \lesssim 95 \text{ GeV}$	$60 \lesssim m_{\tilde{\chi}_2^0} \lesssim 85 \text{ GeV}$
$88 \lesssim m_{\tilde{\chi}_3^0} \lesssim 105 \text{ GeV}$	$88 \lesssim m_{\tilde{\chi}_3^0} \lesssim 108 \text{ GeV}$
$110 \lesssim m_{\tilde{\chi}_4^0} \lesssim 145 \text{ GeV}$	$110 \lesssim m_{\tilde{\chi}_4^0} \lesssim 132 \text{ GeV}$
$62 \lesssim m_{\tilde{\chi}_1^\pm} \lesssim 95 \text{ GeV}$	$65 \lesssim m_{\tilde{\chi}_1^\pm} \lesssim 90 \text{ GeV}$
$100 \lesssim m_{\tilde{\chi}_2^\pm} \lesssim 150 \text{ GeV}$	$100 \lesssim m_{\tilde{\chi}_2^\pm} \lesssim 125 \text{ GeV}$

Table 1: Constraints on the MSSM parameters and masses in the neutralino LSP scenario requiring the total branching ratio  $\text{BR}[\tilde{e}^+\tilde{e}^- \rightarrow e^+e^-\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)] > 50\%$  and the  $\sigma(\tilde{e}\tilde{e}) \times \text{BR} > 4 \text{ fb}$  for  $\tilde{e} = \tilde{e}_L$  and  $\tilde{e} = \tilde{e}_R$ .

ratios. Apart from a possibly light stop  $\tilde{t}_1$ , squarks do not significantly affect our analysis as long as they are heavier than about 200 GeV (which we assume). The Higgs sector is determined by adding the pseudo-scalar mass  $m_A$  to the inputs, but basically decouples for large  $m_A$ . The LEP1 limit on the mass of the lightest neutral Higgs boson  $h$  is sufficient to ensure the  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\gamma$  and not  $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0h$ . For each set of supersymmetric parameters (each allowed “model”) we calculate cross sections for chargino, neutralino and chargino-neutralino pair production at LEP and Tevatron, as well as the branching ratios of all charginos, neutralinos, and sleptons for every allowed channel. It is instructive to separate kinematic constraints from branching ratio constraints. In particular, the combined branching ratio increases as  $M_1 \rightarrow M_2 \rightarrow \sim 60 \text{ GeV}$ , but is virtually independent of  $\mu$ . There is a weak dependence on  $\tan\beta$ , for which larger values tend to increase the mass difference between  $M_1$  and  $M_2$ , thus reducing the total branching ratio. The final set of  $ee\gamma\gamma + \cancel{E}_T$  event constraints on the neutralino LSP scenario is given in Table 1.

The neutralino LSP interpretation with  $\tan\beta \sim 1$ , Higgsino-like  $\tilde{\chi}_1^0$ ,  $\tilde{\chi}_1^\pm$  and  $M_1 \simeq M_2$  is entirely

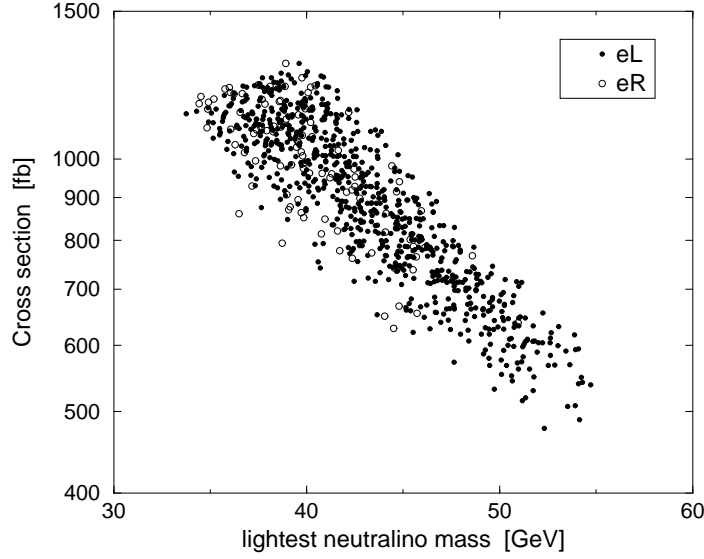


Figure 2: The cross section for  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  production at the Tevatron, for all sets of supersymmetric parameters consistent with the  $ee\gamma\gamma + \cancel{E}_T$  event in the neutralino LSP scenario with a cross section  $\sigma(\tilde{e}\tilde{e}) \times \text{BR}[\tilde{e}^+ \tilde{e}^- \rightarrow e^+ e^- \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)] \gtrsim 4$  fb and separately  $\text{BR} > 50\%$ . The constraints are slightly different for  $\tilde{e}_L$  and  $\tilde{e}_R$ , hence the different symbols representing each case.

satisfactory. It is remarkable that this is the same region of parameter space that provides a SUSY interpretation of the LEP reported  $Z \rightarrow b\bar{b}$  excess ( $R_b$ ) [14]; for that interpretation to be valid (and assuming the  $R_b$  discrepancy persists), the lightest stop must have a mass in the range 45–80 GeV and the branching ratio of top into the light stop must be greater than about 0.45. If both  $R_b$  and the  $ee\gamma\gamma + \cancel{E}_T$  event are considered then  $m_{\tilde{t}_1} < m_{\tilde{\chi}_1^\pm}$ . The potential for observing the indirect production of stop from top decays in such a scenario was considered in e.g. Ref. [15].

There are a number of processes that must occur if the neutralino LSP interpretation is valid. Figs. 2,3 show the cross section for the most promising associated processes  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  and  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  production at the Tevatron, where the total branching ratio for  $\tilde{e}^+ \tilde{e}^- \rightarrow e^+ e^- \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)$  was required to be greater than 50%. The  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  cross section is large and gives events such as  $\tilde{\chi}_1^\pm (\rightarrow l^\pm \nu \tilde{\chi}_1^0) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)$  with a signature  $l^\pm \gamma \cancel{E}_T$ ,  $\tilde{\chi}_1^\pm (\rightarrow jj \tilde{\chi}_1^0) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)$  with a signature  $jj \gamma \cancel{E}_T$ , or  $\tilde{\chi}_1^\pm (\rightarrow \tilde{t}_1 b) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)$  followed by  $\tilde{t}_1 \rightarrow c \tilde{\chi}_1^0$  with signature  $\gamma bc \cancel{E}_T$ . The channel  $\tilde{e}_L \tilde{\nu}_e$



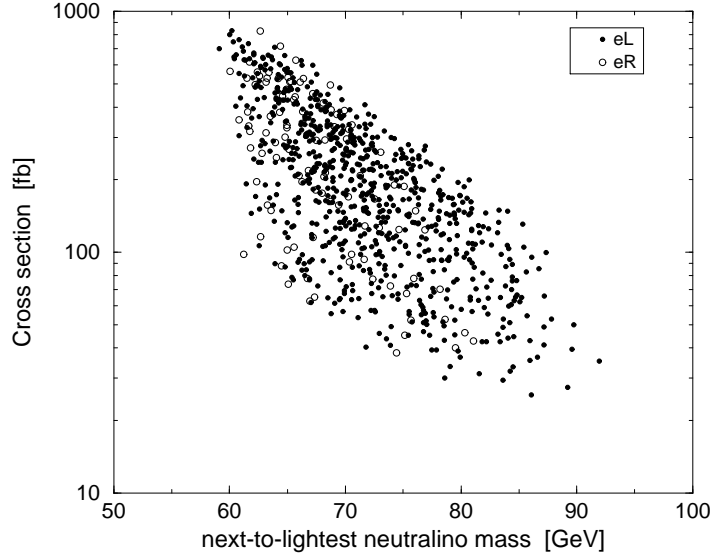


Figure 3: The cross section for  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production at the Tevatron, for all sets of supersymmetric parameters consistent with the  $ee\gamma\gamma + \cancel{E}_T$  event in the neutralino LSP scenario with a cross section  $\sigma(\tilde{e}\tilde{e}) \times \text{BR}[\tilde{e}^+\tilde{e}^- \rightarrow e^+e^-\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)\tilde{\chi}_2^0(\rightarrow \gamma\tilde{\chi}_1^0)] \gtrsim 4$  fb and separately  $\text{BR} > 50\%$ . The constraints are slightly different for  $\tilde{e}_L$  and  $\tilde{e}_R$ , hence the different symbols representing each case.

gives typically  $\tilde{e}_L(\rightarrow e\tilde{\chi}_2^0)\tilde{\nu}_e(\rightarrow \nu_e\tilde{\chi}_2^0)$  followed by  $\tilde{\chi}_2^0 \rightarrow \gamma\tilde{\chi}_1^0$  with a signature  $e\gamma\gamma\cancel{E}_T$  ( $\tilde{\nu}_e \rightarrow e\tilde{\chi}_1^\pm$  and  $\tilde{\nu}_e \rightarrow \nu_e\tilde{\chi}_1^0$  are suppressed because the  $\tilde{\chi}_1^\pm$  and  $\tilde{\chi}_1^0$  are Higgsino-like). The  $\tilde{\nu}_e\tilde{\nu}_e$  channel gives  $\gamma\gamma\cancel{E}_T$ , as does  $\tilde{\chi}_2^0\tilde{\chi}_2^0$  production.

Since we do not assume gaugino mass unification, we cannot determine the gluino mass. If gaugino mass unification were approximately valid for  $M_2$  and  $M_3$  (the non-Abelian gaugino masses), then  $m_{\tilde{g}} \sim 300$  GeV. However, we can mention a few channels with gluinos that could give observable rates. Probably production of  $\tilde{g}\tilde{g}$ ,  $\tilde{g}\tilde{\chi}_2^0$ , and  $\tilde{g}\tilde{\chi}_2^\pm$  will be significant. The  $\tilde{g}$  could decay to  $q\bar{q}\tilde{\chi}_2^0$  or  $q\bar{q}'\tilde{\chi}_2^\pm$  or, if  $\tilde{t}_1$  is light enough,  $\tilde{g} \rightarrow \tilde{t}\tilde{t}_1$ . In general, cascade decays through  $\tilde{\chi}_2^0$  will lead to a nice signature of one or more hard  $\gamma$ 's + multijets +  $\cancel{E}_T$ . One nice signature is  $Wbc\gamma\cancel{E}_T$ , another is  $\gamma bj\bar{j}\cancel{E}_T$ . Similar signatures can come from production of squark plus  $\tilde{\chi}_2^0$ , e.g.  $j\gamma\gamma\cancel{E}_T$ ; the simplest unification arguments, which need not be valid, suggest  $m_{\tilde{q}} \sim 3m_{\tilde{e}}$  (except for  $m_{\tilde{t}_1}$  which could be very light).

## The light gravitino interpretation

The gravitational origins of the interactions of the gravitino might naively lead to the expectation that they can be neglected in collider experiments. However, it was originally pointed out by Fayet [5] that the  $\pm 1/2$  polarization states of the gravitino behave like a Goldstino in global SUSY, and therefore have couplings to (gauge boson, gaugino) and (scalar, chiral fermion) which are inversely proportional to the gravitino mass. In the limit  $m_{\tilde{G}} \rightarrow 0$ , the gravitino is obviously kinematically accessible and has large couplings, and so can have a profound effect on collider searches for SUSY [5, 16, 17, 18]. A gravitino of mass less than about 10 keV avoids certain cosmological problems [19]. More recently, there has been theoretical impetus for the light gravitino coming from considerations of dynamical SUSY breaking [20].

One major point in favor of the hypothesis that  $\tilde{X}_1$  in the  $ee\gamma\gamma + \cancel{E}_T$  event is the light gravitino is that the kinematics with  $m_{\tilde{G}} = m_{\tilde{X}_1} \approx 0$  allows the selectron to be as light as 80 GeV, with a correspondingly larger production cross section. Furthermore, with the mass ordering  $m_{\tilde{G}} \ll m_{\tilde{\chi}_1^0} < m_{\tilde{e}_R}$  or  $m_{\tilde{e}_L}$  the branching fraction should be essentially 100%, with no other adjustment of parameters required. If the lightest neutralino is the second-lightest supersymmetric particle, it nearly always decays through the 2-body mode  $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ . (The 3-body decays  $\tilde{\chi}_1^0 \rightarrow \tilde{G}f\bar{f}$  can also occur, mediated by a virtual Z or a virtual sfermion  $\tilde{f}$  or Higgs scalar, but are suppressed. If  $m_h < m_{\tilde{\chi}_1^0}$  then the two-body decay  $\tilde{\chi}_1^0 \rightarrow h\tilde{G}$  might occur with  $h \rightarrow b\bar{b}$ , but in any case this is suppressed by both phase space and mixing angles if  $\tilde{\chi}_1^0$  is gaugino-like.) If the gravitino is light enough, this means that SUSY signatures will often include two hard photons plus missing energy. The contribution to the neutralino decay width is given by [5]

$$\Gamma(\tilde{\chi}_i \rightarrow \tilde{G}\gamma) = 1.12 \times 10^{-11} \kappa_i (m_{\tilde{\chi}_i^0}/100 \text{ GeV})^5 (m_{\tilde{G}}/1 \text{ eV})^{-2} \text{ GeV}$$

where in the notation of [11]  $\kappa_i = |\sin\theta_W N_{i2} + \cos\theta_W N_{i1}|^2$ . If this decay width is too small,  $\tilde{\chi}_1^0$  will decay outside the detector, and the signature for any given event would be the same as in the usual MSSM. In terms of its energy, the decay distance of  $\tilde{\chi}_1^0$  is given by

$$d = 1.76 \times 10^{-3} \kappa_1^{-1} (E_{\tilde{\chi}_1^0}^2/m_{\tilde{\chi}_1^0}^2 - 1)^{1/2} (m_{\tilde{G}}/1 \text{ eV})^2 (m_{\tilde{\chi}_1^0}/100 \text{ GeV})^{-5} \text{ cm}$$

The maximum  $m_{\tilde{\chi}_1^0}$  which fits the kinematic and cross-sectional criteria of the event is not much larger than 100 GeV, so we find a very rough upper limit of 250 eV on the gravitino mass, by

requiring  $d \lesssim 150$  cm. This limit is decreased by an order of magnitude for smaller  $m_{\tilde{\chi}_1^0}$ . If  $m_{\tilde{G}} \gtrsim (5, 50)$  eV for  $m_{\tilde{\chi}_1^0} = (40, 100)$  GeV, the kinematic analysis described earlier is not valid in detail, since the  $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$  decay length is significant on the scale of the CDF detector. However, within this range it is still true that the event is consistent with a light gravitino. The constraints on the allowed MSSM parameter space in this scenario are essentially just those which follow from the kinematics discussed above.

The light gravitino interpretation suggests several other signatures which can be searched for at the Tevatron and LEP-2. If the gravitino is “superlight” ( $m_{\tilde{G}} \ll 1$  eV), processes with associated production of gravitinos become important. At both LEP and the Tevatron, one has the possibilities of  $\tilde{\chi}_1^0 \tilde{G}$  and  $\tilde{\chi}_2^0 \tilde{G}$  production, leading to signatures  $\gamma \cancel{E}_T$  and  $\gamma l^+ l^- \cancel{E}_T$  or  $\gamma jj \cancel{E}_T$  respectively. The non-observation of  $\gamma \cancel{E}_T$  events in  $Z$  decays at LEP1 probes (albeit in a quite mixing angle-dependent way) values of  $m_{\tilde{G}}$  up to about  $10^{-5}$  eV, for  $m_{\tilde{\chi}_1^0} < m_Z$  [16, 21]. (One might also have a single photon signature in the neutralino LSP scenario, from  $\tilde{\chi}_2^0 \tilde{\chi}_1^0$  production, but this seems to be strongly disfavored by the mixing angle requirements.) At hadron colliders, one can have  $\tilde{g} \tilde{G}$  [17] production. If  $m_{\tilde{G}} < 10^{-2}$  eV and squarks are very heavy,  $\tilde{g}$  can decay dominantly into  $g + \tilde{G}$  with a monojet signature, although the signal will probably be below background unless  $m_{\tilde{G}} < 10^{-5}$  eV. Another possibility is  $\tilde{\chi}_1^\pm \tilde{G}$  production with the signature  $l^\pm \gamma \cancel{E}_T$  or  $\gamma jj \cancel{E}_T$ .

Other signals which can occur either at the Tevatron or LEP-2 should contain 2 energetic photons (assuming that one takes the  $ee\gamma\gamma + \cancel{E}_T$  event as establishing that  $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$  occurs within the detector at least a large fraction of the time). One obvious signal is  $\gamma\gamma \cancel{E}_T$ , which will follow from  $\tilde{\chi}_1^0 \tilde{\chi}_1^0$  or  $\tilde{\nu}\tilde{\nu}$  production. The signal  $l^\pm \gamma \cancel{E}_T$  can occur from either  $\tilde{l}_L^\pm \tilde{\nu}$  or  $\tilde{\chi}_1^\pm \tilde{\chi}_1^0$  production. The  $\tilde{\nu}_e \tilde{\nu}_e$  and  $\tilde{e}_L \tilde{\nu}_e$  modes are unavoidable if the  $ee\gamma\gamma + \cancel{E}_T$  event is due to  $\tilde{e}_L$  pair production. It should be noted that in the light gravitino scenario, there are actually several processes that can lead to the signature  $l^+ l^- \gamma \cancel{E}_T$ ; besides the obvious  $\tilde{e}_R \tilde{e}_R$  and  $\tilde{e}_L \tilde{e}_L$ , one has also  $\tilde{\chi}_1^0 \tilde{\chi}_2^0$  production or even  $\tilde{\nu}\tilde{\nu}$  or  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  (although it seems more difficult to reconcile these possibilities with the observed kinematics of the  $ee\gamma\gamma + \cancel{E}_T$  event). In the cases of  $\tilde{\nu}\tilde{\nu}$  and  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  production, the two leptons in the signature need not be the same flavor. One also has  $\gamma\gamma jj \cancel{E}_T$  from either  $\tilde{\chi}_1^0 \tilde{\chi}_2^0$  or  $\tilde{\chi}_1^0 \tilde{\chi}_1^\pm$  production. Another possible discovery signature is  $l^+ l^- l^\pm \gamma \cancel{E}_T$

following from either  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  or  $\tilde{l}_L^\pm \tilde{\nu}$  production. In general, one can search for any of the usual SUSY signatures with an additional pair of energetic photons (one from each  $\tilde{\chi}_1^0$  decay). If  $\tilde{g}\tilde{g}$  is accessible, it can lead to the usual multijet +  $\cancel{E}_T$  signal, but with 2 energetic photons. If a stop is light, another possibility is the production of  $\tilde{\chi}_1^\pm (\rightarrow \tilde{t}_1 b) + \tilde{\chi}_1^0 (\rightarrow \tilde{G}\gamma)$ , followed by  $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 (\rightarrow \tilde{G}\gamma)$ , that gives a signature  $bc\gamma\gamma\cancel{E}_T$  at the Tevatron, and does not seem to have a counterpart for the neutralino LSP scenario. Each of the signatures listed above can occur also with only one hard photon if  $d$  is comparable to the size of the detector, allowing one of the two decays  $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$  to be missed. While the neutralino LSP interpretation and the light gravitino interpretation both predict signatures with 2 energetic photons and  $\cancel{E}_T$ , the rates and kinematics will be different and so may eventually be used to distinguish them. Furthermore, if  $m_{\tilde{G}}$  is in the upper part of the range favored by dynamical supersymmetry breaking [20], it is not unlikely that the decay length  $d$  can eventually be measured in the detector. While we were preparing this paper, two papers [6, 22] have appeared which discuss light gravitino signals inspired by dynamical supersymmetry breaking.

## LEP constraints and predictions for the neutralino LSP scenario

In constraining the parameters of the supersymmetric Lagrangian (e.g. superpartner masses and couplings), we imposed present LEP1–1.3 constraints and found a region of parameter space that can explain the  $ee\gamma\gamma + \cancel{E}_T$  event with correct kinematics and cross section. Selectron pair-production is never allowed at LEP1.3, since the kinematics of the  $ee\gamma\gamma + \cancel{E}_T$  event forces  $m_{\tilde{e}} > 80$  GeV. The light neutralino pair-production processes are suppressed for dynamical reasons. Indeed, although it is possible that  $m_{\tilde{\chi}_1^0} < M_Z/2$ , invisible  $Z \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$  decays give a contribution to  $\Gamma(Z)_{\text{inv}}$  below the experimental sensitivity, since  $\tilde{\chi}_1^0 \simeq \tilde{H}_b^0$  and the coupling  $Z\tilde{H}_b^0\tilde{H}_b^0$  is suppressed like  $\cos 2\beta$  when  $\tan \beta \rightarrow 1$ . Furthermore, even if  $m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0}$  is below 130 GeV, the  $\tilde{\chi}_1^0 \tilde{\chi}_2^0 \simeq \tilde{H}_b^0 \tilde{\gamma}$  pair production is strongly depleted (to the level of a few fb) at LEP1.3 by the absence of  $Z\tilde{\gamma}\tilde{H}_i^0$  and  $e^\pm \tilde{e}_{L,R}^\mp \tilde{H}_i^0$  ( $m_e \rightarrow 0$ ) couplings in the theory. Finally,  $\tilde{\chi}_2^0 \tilde{\chi}_2^0$  production is either kinematically forbidden or, where allowed, it is negligible at LEP1.3, since  $\tilde{\gamma}\tilde{\gamma}$  pairs can only be produced by t-channel  $\tilde{e}_{L,R}$ -exchange and  $m_{\tilde{e}_{L,R}}$  is sufficiently large to suppress this rate. The main constraints from non-observation of supersymmetric events at LEP1.3 are from  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$

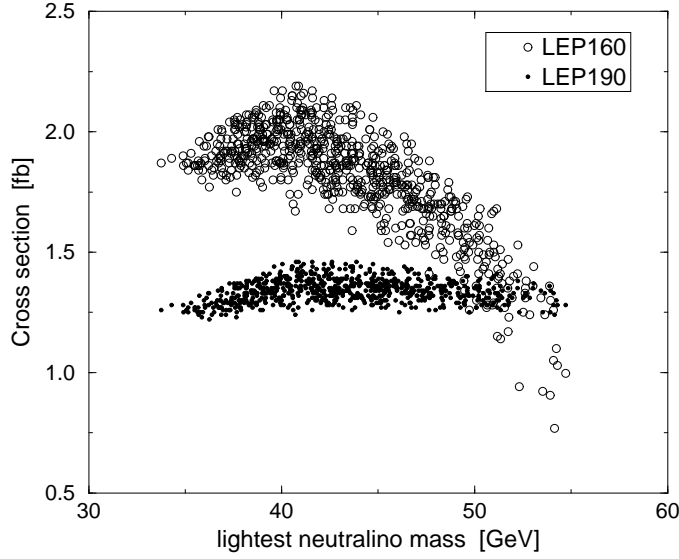


Figure 4: The cross section for  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  production (before initial-state radiation corrections) at the LEP160 and LEP190 for sets of supersymmetric parameters consistent with the  $ee\gamma\gamma + \cancel{E}_T$  event in the neutralino LSP scenario with a cross section  $\sigma(\tilde{e}\tilde{e}) \times \text{BR}[\tilde{e}^+ \tilde{e}^- \rightarrow e^+ e^- \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0) \tilde{\chi}_2^0 (\rightarrow \gamma \tilde{\chi}_1^0)] \gtrsim 4 \text{ fb}$  and separately  $\text{BR} > 50\%$ . In both  $\tilde{e}_L$  and  $\tilde{e}_R$  cases, the cross section lies in the region shown.

production. The  $\tilde{\chi}_3^0$  is in general a mixture  $\tilde{Z} - \tilde{H}_a^0$ , with dominant “antisymmetric”-Higgsino  $\tilde{H}_a^0$  component and it can be easily produced in association with  $\tilde{\chi}_1^0 \simeq \tilde{H}_b^0$  through s-channel  $Z$ -exchange. Since the presence of the  $ee\gamma\gamma + \cancel{E}_T$  event is not compatible with high values of  $|\mu|$  (see Table 1), one has to choose  $M_1 \simeq M_2 \simeq m_{\tilde{\chi}_2^0}$  values large enough to push  $m_{\tilde{\chi}_3^0}$  close to or above the threshold. In particular, we require  $\sigma(e^+ e^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_3^0) < 2 \text{ pb}$  at LEP1.3 (after an evaluation of the initial-state radiation effects), leading to a very small (less than 10) total number of  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  events expected in the data of an ideal LEP1.3 “hermetic” detector. Further, about 20% of these events are invisible because of the  $\tilde{\chi}_3^0 \rightarrow \nu \bar{\nu} \tilde{\chi}_1^0$  branching ratio. At LEP1.3,  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  production is kinematically forbidden for some ranges of masses, while charginos are too heavy to be detected (see Table 1).

In the following, we discuss the phenomenology at two future phases of LEP with energies  $\sqrt{s} = 160, 190 \text{ GeV}$  and an expected luminosity of about 10, 500  $\text{pb}^{-1}$  respectively. At LEP190, although selectron-pair production is out of reach, we expect clear and visible supersymmetric

signals from light neutralinos and charginos. The dynamical suppression of the  $\tilde{\chi}_1^0\tilde{\chi}_2^0$  production is still effective (giving a total rate of the order of 10 fb both at LEP160 and LEP190) and the radiative channel  $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0\gamma$  [23] should remain well below the  $\nu\bar{\nu}\gamma$  SM background for the same reason the  $Z \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$  channel is suppressed at LEP1. The  $\tilde{\chi}_2^0\tilde{\chi}_2^0$  production is also suppressed by  $m_{\tilde{e}_{L,R}}$  and is always well below the visibility threshold at LEP160 for the expected integrated luminosity [ $\sigma(e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0) \lesssim 0.5$  pb]. Some interesting signals from this channel are possible at LEP190 when  $m_{\tilde{\chi}_2^0} \lesssim 80$  GeV leading to production rates for  $\tilde{\chi}_2^0\tilde{\chi}_2^0$  production through  $\tilde{e}_{L,R}$  exchange at the level of hundreds of events, with a distinctive  $\gamma\gamma +$  large  $\cancel{E}$  signature.

The most promising channels are again  $\tilde{\chi}_1^0\tilde{\chi}_3^0$  production and  $\tilde{\chi}_1^+\tilde{\chi}_1^-$  production. Nevertheless, the cross section for the former is generally below 2 pb at LEP160 (because of the normal drop of the s-channel contribution when one goes away from the  $Z$  peak) and might not be large enough for detection; nevertheless the large integrated luminosity at LEP190 should allow one to disentangle this supersymmetric signal from the background (see Fig. 4). The total cross section for  $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_3^0$  is of the order of 1–1.5 pb at  $\sqrt{s} = 190$  GeV for the whole region of the parameter space suggested by the  $ee\gamma\gamma + \cancel{E}_T$  event. We checked that initial-state radiation effects can deplete the cross section at LEP160 by at most 20%, and are generally not significant at LEP190. The large Higgsino component of the  $\tilde{\chi}_3^0$  makes the coupling  $\tilde{\chi}_1^0\tilde{\chi}_3^0Z$  generally dominant over  $\tilde{\chi}_2^0\tilde{\chi}_3^0Z$  and those involving sfermions, while the decay channels  $\tilde{\chi}_3^0 \rightarrow \tilde{\chi}_1^\pm l^\mp \nu$  or  $\tilde{\chi}_1^\pm q \bar{q}'$  (though dynamically enhanced by a large charged Higgsino component in  $\tilde{\chi}_1^\pm$ ), have in general little available phase space [low  $(m_{\tilde{\chi}_3^0} - m_{\tilde{\chi}_1^\pm})$ ]. Hence, the main signature will be  $\tilde{\chi}_1^0\tilde{\chi}_3^0 \rightarrow f\bar{f} + (\cancel{E}, \cancel{p}_T)$ , where  $f\bar{f}$  refers to a pair of jets (branching ratio about 60-65%) or charged leptons (branching ratio about 2-3% per family). This signal, of course, has to compete with a large  $W^+W^-$  SM background, but should allow a confirmation or refutation of the neutralino LSP scenario.

The cross section for chargino pair production depends on the sneutrino exchange contribution, interfering destructively with the  $Z$ -exchange contribution. If the  $ee\gamma\gamma + \cancel{E}_T$  event is a result of  $\tilde{e}_R^+\tilde{e}_R^-$  production, then the sneutrino mass is not constrained, hence the cross section is not uniquely determined by the chargino mass. We find the maximum cross section for  $\tilde{\chi}_1^+\tilde{\chi}_1^-$

production at LEP160 is about 3 pb when  $m_{\tilde{\chi}_1^\pm}$  is close to its minimum allowed value and  $m_{\tilde{\nu}_e}$  is large. However, larger chargino masses (above the threshold of LEP160) are not excluded in the neutralino LSP scenario. If the  $ee\gamma\gamma + \cancel{E}_T$  event is from  $\tilde{e}_L^+ \tilde{e}_L^-$ , then  $m_{\tilde{\nu}_e}$  is fixed by  $m_{\tilde{e}_L}$  and the sum rule given previously, with a range determined by  $\tan\beta$ . We find that  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  detection is unlikely at LEP160 because the cross section is always below 1.5 pb, since the sneutrino is light. At LEP190, the cross section is always at least 0.5 pb and the chargino should be detectable with the expected integrated luminosity. For the signature one has to distinguish between two completely different cases, with the stop lighter or heavier than the chargino. In the light stop case ( $m_{\tilde{\chi}_1^\pm} > m_{\tilde{t}_1} + m_b$ ) one has always  $\tilde{\chi}_1^\pm \rightarrow \tilde{t}_1 b$ , followed by  $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ , with  $b\bar{b}c\bar{c} + \cancel{E}$  resulting signature. In the other case, since the  $\tilde{\chi}_1^\pm$  is mainly charged Higgsino, the dominant channel is  $\tilde{\chi}_1^\pm \rightarrow q\bar{q}'\tilde{\chi}_1^0$  (about 60–65%) or  $\tilde{\chi}_1^\pm \rightarrow l^\pm \nu \tilde{\chi}_1^0$  (10–12% for each lepton  $e, \mu, \tau$ ) through a virtual  $W$  (when open,  $\tilde{\chi}_1^\pm \rightarrow f\bar{f}'\tilde{\chi}_2^0$  is also disfavored by kinematics). So the main signatures are  $j\bar{j}j\bar{j}\cancel{E}$  or  $l^\pm j\bar{j}\cancel{E}$ ,  $l^+ l'^- \cancel{E}$ . Thus, LEP160 might see superpartners, but the neutralino LSP interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event cannot be excluded by non-observation. However, LEP190 should detect  $\tilde{\chi}_1^0 \tilde{\chi}_3^0$  and/or  $\tilde{\chi}_1^+ \tilde{\chi}_1^-$  (and probably also  $\tilde{\chi}_2^0 \tilde{\chi}_2^0$ ) pairs, thus confirming or excluding the neutralino LSP scenario.

## Conclusions and final remarks

We have seen that the selectron interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event can be made in two different supersymmetric scenarios, which ultimately have different sources of supersymmetry breaking. The generalized MSSM with a neutralino LSP can accommodate the event if  $1 \lesssim \tan\beta \lesssim 3$  and  $M_1 \simeq M_2$ ; gaugino mass unification cannot be satisfied. These constraints do not apply in the light gravitino scenario. It is interesting that in the neutralino LSP scenario both the  $ee\gamma\gamma + \cancel{E}_T$  event and the SUSY interpretation of  $R_b$  independently push the parameters into the same region of parameter space, as discussed in the text.

It is unnecessary to emphasize the importance of the CDF  $ee\gamma\gamma + \cancel{E}_T$  event if it is indeed from selectron production. It is presently possible to maintain a supersymmetric interpretation even when the event is examined in detail. We will describe the details of the model building, parameter space constraints, and many aspects of collider predictions for both the neutralino

LSP scenario and the light gravitino scenario in a larger paper [7]. Our main goal here is to argue that if the interpretation is correct, then a number of other events must occur at the Tevatron, and some at LEP190. If none of these are observed, it would rule out the supersymmetric interpretation of the  $ee\gamma\gamma + \cancel{E}_T$  event as selectron production. While some of the signatures can have backgrounds, the combination of one or more hard photons with missing energy implies the background rates are probably not large. If the confirming events are there, then most other superpartners are being produced at Fermilab, and some will be produced at LEP190. Luminosity at the Tevatron and LEP should lead to the opportunity to detect a number of these important states.

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